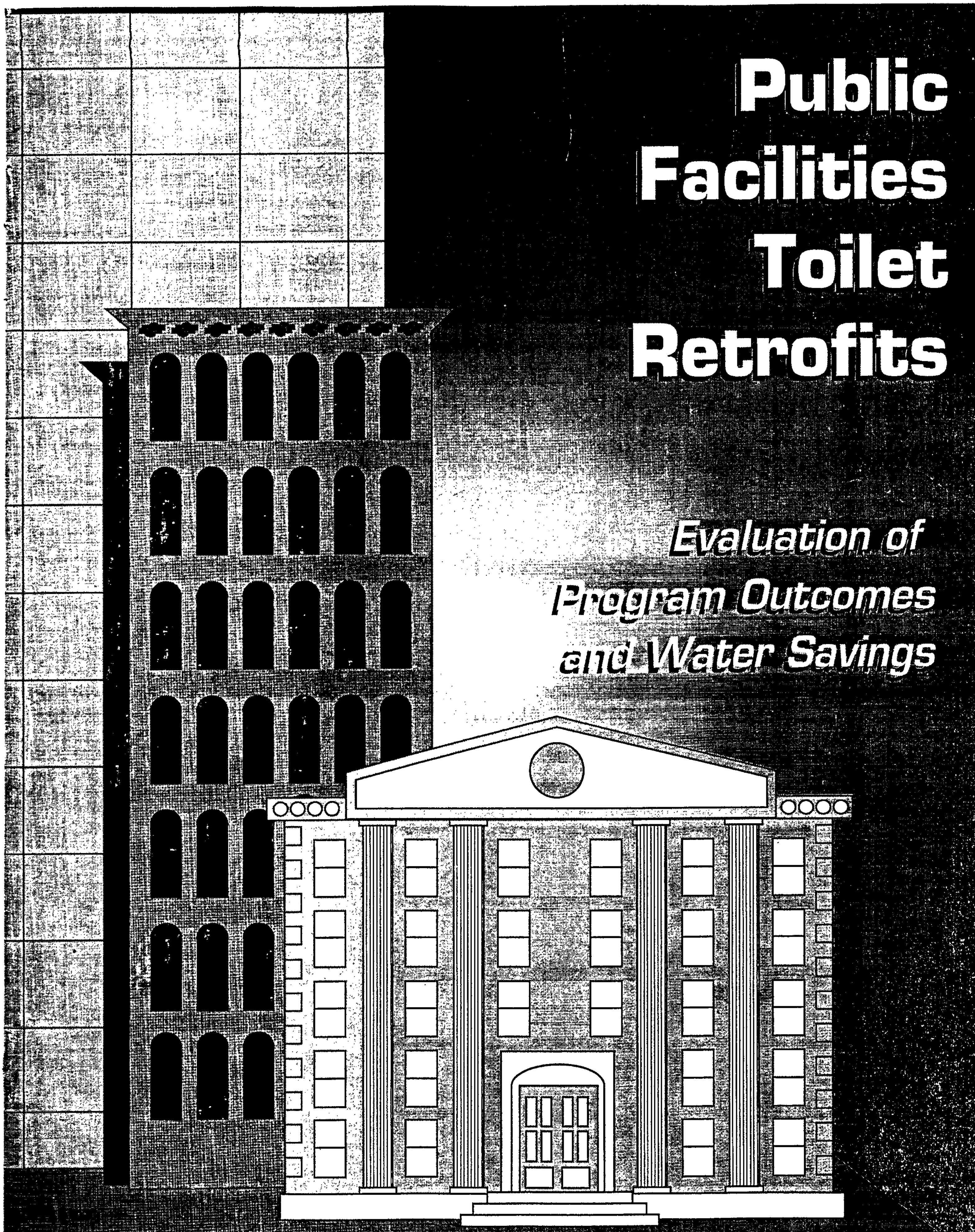
Public Facilities Toilet Retrofits

Evaluation of Program Outcomes and Water Savings



A & N Technical Services, Inc.

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WATER SAVINGS FROM NON-RESIDENTIAL TOILET RETROFITS: AN EVALUATION OF THE CITY OF SAN DIEGO'S PUBLIC FACILITIES RETROFIT PROGRAM

December 1994

A Report Submitted to
The Metropolitan Water District of Southern California
350 South Grand Avenue
Los Angeles, CA 90071

By

Anil Bamezai
Thomas W. Chesnutt

PREFACE

In July 1992, the City of San Diego Water Utilities Department initiated a toilet retrofit program to replace over 1,800 toilets in 350 public buildings with new 1.6 gallons-per-flush toilets. By March 1994, approximately 195 buildings had been retrofitted. The Public Facilities Retrofit program was funded jointly by the San Diego County Water Authority and the Metropolitan Water District of Southern California. The City of San Diego was an early participant in the program. Since then additional member agencies within San Diego County have also initiated similar public-institution toilet retrofit programs.

This study was undertaken to quantify water savings achieved through the toilet retrofit program, as well as to identify the factors that drive water savings from toilet retrofits in the non-residential sector. The results of this study should be of significant relevance to water conservation managers and water resource planners who are contemplating plumbing retrofit programs in the non-residential sector.

EXECUTIVE SUMMARY

In the summer of 1992, the San Diego County Water Authority entered into program agreements with the City of San Diego and the County of San Diego to retrofit toilet fixtures at select public facilities with ultra low-flush (ULF) toilets. Funds for the plumbing fixtures were provided jointly by the San Diego County Water Authority and the Metropolitan Water District of Southern California. Project administration and installation costs were borne by the City of San Diego.

In response to the success of this pilot program implemented in FY 1992-93, a questionnaire was distributed to all the member agencies of the San Diego County Water Authority to gauge their interest in participating in the next phase of the program. The response was overwhelmingly enthusiastic. In addition to the City of San Diego, several public agencies located within the service areas of seven of the County Authority's member agencies opted to participate in this second program phase. The program continues to remain very popular and additional phases have since been planned or implemented.

Under the auspices of the Public Facilities Toilet Retrofit program, the City of San Diego earmarked 350 public buildings containing over 1,800 toilets for retrofits with 1.6 gallons-per-flush toilets. The program began in July 1992. By March 1994, roughly 195 buildings had been retrofitted. This study focuses on water savings achieved from only the City's retrofit efforts because these sites were retrofitted the earliest. Only these sites had sufficiently long post-retrofit billing data available. Even so, water savings could not be analyzed for all these 195 sites. In many instances either the building-specific billing histories were unavailable because of master metering, or the data were incomplete. Based upon a detailed statistical evaluation of 70 sites for which complete data was available, we conclude that this program was very effective at saving water. Almost all of the pre-existing toilets in the analyzed sites used 3.5 gallons per flush. On average, the replacement of these pre-existing toilets saved approximately 76.8 gallons per toilet per day. This impressive water-savings performance is superior to what has been achieved through toilet retrofit programs in the residential sector.

We found considerable variation in water savings achieved by toilet retrofits across the different sites analyzed in this study. We could identify four distinct subgroups that appeared to differ in the level of achieved savings: 1) Police Stations; 2) Fire Stations; 3) Libraries; and 4) the residual group consisting of Pools, Comfort Stations, Recreation Centers, Senior Centers and other miscellaneous sites. None of the public buildings classified as "Offices" could be analyzed because of insufficient data.

This variation in water savings creates tremendous problems for forecasting the efficacy of non-residential toilet retrofit programs. However, the variation in water savings also followed some very predictable patterns. Some of the key factors that appeared correlated with water savings are:

1) number of toilets;
2) number of urinals;
3) number of full-time employees and visitors;
4) the amount of time visitors spend at a particular site;
5) the number of hours per day and days per week a facility is operational.

The flushing volume of existing toilets is also obviously a key predictor of water savings. Almost all toilets in the analyzed public facilities used 3.5 gallons per flush prior to the retrofit.

Toilet retrofits in Police Stations were the least effective, saving only slightly over 20 gallons per toilet per day. The estimate for Police Stations is not as precise as for the other three sub-groups because only three Police Stations were retrofitted with toilets. But, the low water savings estimate is not surprising. Police Stations were equipped with the largest number of toilets and urinals among all the analyzed sites, even though over half to two-thirds of the full-time staff is usually assigned to patrol duty. The net result of more toilets and less use is less savings per toilet.

Water savings achieved in Fire Stations was slightly higher—approximately 28.3 gallons per toilet per day. Few toilets and even fewer urinals, combined with a round-the-clock operational schedule, were largely responsible for these higher savings even though the staffing level in Fire Stations is lower than Police Stations.

Toilet retrofits in Libraries saved approximately 75.9 gallons per toilet per day. These Libraries cater to a large number of visitors and have relatively few toilets and urinals. All these factors drive the savings per toilet upward.

The greatest savings were achieved by toilet retrofits in sites such as Recreation Centers, Senior Centers, Pools, Comfort Stations and other miscellaneous sites. On average toilet retrofits in these sites saved approximately 116.8 gallons per toilet per day. Again, the large number of individuals who have contact with these sites is the primary explanation for these high savings. The relatively long time that individuals spend at public sites such as Recreation Centers and Senior Centers compared to, say, Libraries is perhaps an additional reason for higher water savings per toilet.

Although water savings can also be expressed on a per-capita basis, it's very difficult to interpret these per-capita estimates given that some sites have no visitors while some sites cater predominantly to visitors. We provide these estimates in Section II only for comparison purposes.

This study's results suggest that considerable attention should be paid to targeting non-residential buildings in accordance with their water savings potential when designing future retrofit programs. Even though the average water savings achieved through the Public Facilities Retrofit Program was very impressive, averages can be misleading.

Furthermore, this study's results clearly point to the folly of applying simplistic formulas for deriving water savings from non-residential toilet retrofit programs. Water savings potential varies considerably across sites, fortunately in predictable ways. The determinants of toilet-retrofit water savings have been identified here and in previous studies. In addition to the determinants highlighted in this study, gender composition of both employees and visitors at a public site is likely to be another important factor that should be taken into account. Information about gender was not available in this study. For the design of cost-effective non-residential toilet retrofit programs, non-residential sites must be classified according to the factors that drive water savings. Available classification schemes such as the *Standard Industrial Classification* (SIC) codes may not be very useful in predicting conservation potential. Future research must attempt to create a more meaningful schema that classifies non-residential sites according to their water savings potential. Such a schema would be invaluable in targeting future non-residential retrofit programs to further boost their effectiveness, and for reliably estimating water savings.

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ACKNOWLEDGMENTS

Information about the public sites earmarked for retrofits was scarce. This would have been a serious impediment had the City of San Diego Conservation Program staff not shown as much care as they did in collecting this scarce information with the greatest possible accuracy.

We would like to thank Marsi Steirer (City of San Diego) and Maria Mariscal (San Diego County Water Authority) for appreciating our evaluation needs and for ensuring that accurate data collection was fully integrated into the program's mission right from the start. In addition, we would like to acknowledge John Harley's contributions in implementing the program, in ensuring proper data collection, and for spending numerous hours over the phone conveying his real-world insights to us.

The toilet retrofit program could not have been carried out without the joint cooperation and sponsorship of the City of San Diego, San Diego County Water Authority and the Metropolitan Water District of Southern California (MWD). We thank them for all their help. We would specifically also like to thank John Wiedmann and Michael Moynahan of MWD's State Water Project and Conservation Division for giving us the opportunity to undertake this evaluation. This study greatly benefited from their enthusiasm and support.

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TABLES

I. PROGRAM DESCRIPTION

Introduction

The City of San Diego is acutely aware that it is dependent upon imported water for 90 percent of its water needs. The City's vulnerability to periods of cyclical drought in combination with a rapidly growing urban population has motivated the City to undertake numerous water conservation measures. These include interior plumbing and toilet retrofit programs, audit programs and public education programs. Retrofit of existing toilets in public facilities with new 1.6 gallons per flush (gpf) toilets is one of the important conservation programs being pursued by the City of San Diego.

Approximately 350 public facilities with over 1,800 toilets were earmarked for toilet retrofits under the auspices of the Public Facilities Retrofit Program which began in July of 1992. To date, approximately 195 public facilities have been retrofitted with ultra-low-flush toilets. The showerheads and urinals in these earmarked facilities will also be retrofitted, but at a later stage. From an evaluation perspective this is fortuitous. Evaluation of toilet retrofit water savings is a bit more straight-forward and robust because toilet retrofit savings do not have to be separated from showerhead and urinal retrofit savings.

Most of the pre-existing 5-7 gpf flushometer toilets had been retrofitted with 3.5 gpf valves earlier. As a result, almost all of the pre-existing toilets that were retrofitted in these public facilities were flushing 3.5 gallons. No firm records are available about the dates when 5-7 gpf valves were retrofitted with 3.5 gpf valves, but anecdotal evidence suggests about 3-4 years prior to the beginning of the Public Facilities Retrofit Program.

The public facilities retrofitted to date are a diverse group in terms of the functions being performed at these sites and the volumes of people that are either present full-time at the site, or have occasional contact with the site. Broad characteristics of retrofitted public buildings are described next.

Characteristics of Retrofitted Sites

Evaluation of water savings achieved through toilet retrofits in public facilities is complicated for many reasons.

First, in many instances the water use of these public buildings is master metered along with other public spaces. For example, a comfort station may be on the same meter as a large park surrounding it. In many instances it was unclear which particular meter was feeding a public building. Of the 195 public facilities retrofitted to date, water meter connections could be identified for only 118 sites. It has also been established that for the remaining 155 (350-195) sites that have not been yet retrofitted, water meter information will not be available. The program was structured so that smaller stand-alone public buildings would be retrofitted earlier. Larger, more complicated sites, such as parks were scheduled for retrofits later in the program. Thus, this evaluation is based on the maximum usable data available from the Public Facilities Retrofit Program.

Second, the proportion of full-time personnel to visitors can vary greatly from site to site, as can the time spent by visitors at a public site. In such circumstances, making reasonable assumptions about frequency of toilet use becomes doubly difficult. Currently, no reliable estimates are available about how frequently employees or visitors use the restrooms at public sites such as libraries, pools, comfort stations, and so on.

Third, the gender composition of individuals visiting restrooms at public sites impacts toilet use considerably. The presence of urinals in men's restrooms reduces the frequency of toilet use. Unfortunately, data on gender composition of employees and visitors at each site were unavailable.

Fourth, public buildings vary in terms of the number of hours and days they are operational. Fire stations are operational with the same number of staff twenty four hours a day, seven days a week. Police stations are somewhat similar to fire stations in that they are operational around the clock. But, unlike fire stations, police stations have a core full-time staff that keeps only regular office hours and a large proportion of staff that is on patrol duty. At the other end of the spectrum are office buildings that are operational for eight hours a day, five days a week. Because of all these complications, a statistical evaluation of water savings is perhaps the only reliable way of estimating water savings from toilet retrofits at public sites.

Table I-1 describes key characteristics of the 118 sites for which we received data from the City of San Diego. As discussed in the next section, not all these sites could be used for evaluation of water savings because of incomplete data.

Descriptive statistics presented in Table I-1 were collected through a questionnaire that was specifically developed for this project (Appendix C). The questionnaire was also used to collect information about factors that affect outdoor water use such as turf area and irrigation system type, and dates when existing toilets were retrofitted with new 1.6 gpf toilets.

Retrofitted sites were classified into ten categories. Average characteristics of sites falling in each of these ten categories differ considerably (Table I-1). Thus, one would expect toilet retrofit water savings to also vary considerably among these ten categories. For example, libraries in our sample cater to a large number of visitors compared to their full-time staff, but do not have very many toilets or urinals. Thus, toilet usage is likely to be very frequent, leading to large water savings per toilet. For similar reasons, toilet retrofits in Comfort Stations and Recreation Centers would also be expected to save considerable amounts of water.

On the other hand, we would speculate that water savings per toilet retrofit in Police Stations may be toward the lower end of the spectrum given the presence of large numbers of toilets and urinals and the large amount of time spent by police officers patrolling their service areas. The counter-argument is that police stations being operational around the clock should lead to greater water savings.

The purpose of this study is to move away from these speculations. The data in Table I-1 certainly provide clues as to how water savings are likely to vary across different public buildings. But, only a detailed evaluation can confirm or refute these speculations. We turn to the statistical analyses performed to evaluate water savings next in Section II.

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Table I-1 Average Characteristics of Retrofitted Buildings that Impact Water Savings

Building Type	Number of Sites	Number of Toilets Per Site	Number of Urinals Per Site	Number of Employees Per Site	Number of Visitors Per Site Per Day	Days Operational Per Week
Library	28	4.4	0.8	17.2	496	6.2
Offices	12	12.2	4.2	76.2	33	5.3
Police Stations	3	14.0	6.0	194.3	40	7.0
Pool	4	6.0	1.3	11.3	183	7.0
Fire Stations	18	2.7	1.1	14.1	0	7.0
Lifeguard	3	1.0	0.0	3.0	0	7.0
Comfort Station	3	5.3	1.7	2.0	633	7.0
Recreation Center	25	5.3	1.4	9.2	281	6.2
Utility Yard	2	5.5	3.0	60.0	0	6.0
Other	20	5.5	1.7	36.0	72	5.8
OVERALL	118	5.6	1.6	27.4	216	6.2

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II. ESTIMATION OF WATER SAVINGS

Evaluation Strategy

Statistical evaluation of water conservation programs implemented during an ongoing drought raises many difficult technical questions about separating the net impact of the program from ongoing conservation in response to the drought. Drought conditions can alter water use patterns of public facilities in somewhat unpredictable ways. Two public facilities with comparable water use levels prior to the drought may end up conserving very different amounts of water during the drought. Drought response differences among public facilities may stem from differences in either their site characteristics (e.g., turf area) or differences in other difficult-to-measure factors such as pressure from City officials and facility management to adopt a leadership conservation role. How well the analyses capture differences in drought response across public facilities can strongly influence estimates of net program impacts. These issues were carefully examined and then accounted for in the statistical analyses.

Most evaluations rely on survey data that do not and cannot collect information about every factor that affects a customer's water use. The evaluation approach adopted in this study explicitly takes into account unmeasured site characteristics that could affect water use. This feature is especially important because detailed data about factors that affect water use in public buildings were unavailable.

A simple comparison of water use before and after the toilet retrofits cannot distinguish between water saved because of toilet retrofits and water saved in response to the drought. One technique for circumventing this problem is to compare gross water savings of participants to gross water savings of a control group that did not participate in the Public Facilities Toilet Retrofit program. The difference between gross savings of the participants and control sites then is the estimate of the net impact of the audit program.

In the present case we adopted a slightly different strategy. Because almost all public facilities have been earmarked for toilet retrofits, a control group of comparable sites that will never be retrofitted through the program was unavailable. However, since participant public buildings were retrofitted on a staggered schedule (July 1992 through March 1994) we are able to use later participants as controls for earlier participants. Sites earmarked for toilet retrofits after March 1994 could not be used as a control group because information about water meters for these sites was unavailable. Based upon extensive sensitivity analyses, we conclude that even in the absence of a control group our modeling strategy yields relatively unbiased estimates of net program impacts. If net program impacts are biased at all, the bias is likely downward. These issues are discussed in greater detail in Appendix A.

Water savings achieved through the Public Facilities Toilet Retrofit program are evaluated using a fixed-effects statistical model that relates water use to climate, season, size of turf area, type of irrigation system, and an indicator variable for each public site included in the analysis. The site-specific indicator variables (fixed effects) capture the impact of all unmeasured site characteristics that affect water use. Additional interactions among these variables are also included in the statistical model.

The detailed structure of the fixed-effects statistical model, and its estimation, are described in detail in Appendix A. We turn directly to the results of these statistical analyses next.

Net Reduction in Water Use From Public Facility Toilet Retrofits

As discussed in Section 1, water meter information was available for only 118 sites out of the 195 sites retrofitted to date. But due to additional missing data, only 70 of the 118 sites could be used to evaluate water savings. For several reasons, we were able to estimate water savings with high precision in spite of the relatively small sample size. First, information collected about the sites, if complete, was very accurate. Second, 31 out of the 70 analyzed sites either had no turf, or had outdoor irrigation on a separate meter. Greater climatic variation in water use usually degrades statistical precision while determining the net impact of a water conservation program.

Some of the reasons for which specific sites had to be excluded from the water savings analysis are described below:

- Most of the excluded sites were master-metered with other indoor and outdoor areas whose characteristics were unavailable.
- A few sites were excluded because they were master-metered with very large turf areas (e.g., a golf course). Usually the size of these large turf areas was also unavailable.
- One site with large numbers of toilets had to be excluded because the retrofits had been staggered over a long period of time. The building had also undergone a water-intensive asbestos removal process during 1989-90, tainting the pre-retrofit water use history. All this considerably reduced the pre- and post-retrofit water use data available for analysis.
- Several retrofitted sites were not in use. They were closed for restoration.

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Table II-1 Estimate of Net Water Savings by Type of Site

Category (Number of Sites)	Percent Reduction in Water Use (1)	Daily Pre-Retrofit Water use (gals.) (2)	Net Water Savings Per Day (gals.) (3)	Average Number of Toilets Per Site (4)	Average Number of Urinals Per Site (5)	Average Full-Time Staff Per Site (6)	Average Visitors Per Site (7)	Daily Water Savings Per Toilet (gals.) (8)	Daily Water Savings Per Capita (gals.) (9)	Inferred Daily Flushes Per Capita (10)
Police Stations (3)	5.23 %	5498	287.5	14.0	6.0	194.3†	40.0	20.5	1.2	0.6
Fire Stations (13)	9.10 %	901	82.0	2.9	1.2	14.4‡	0.0	28.3	5.7	3.0
Libraries (23)	14.48 %	1574	227.9	3.0	0.6	6.8	428.3	75.9	0.5	0.3
Other (31)¥	24.10 %	2279	549.2	4.7	1.6	9.6	272.8	116.8	1.9	1.0
Overall (70)	16.96 %	1949	330.5	4.3	1.4	18.4	256.2	76.8	1.2	0.6

NOTES:

Net Daily Water Savings — Column (3) = Column (1) × Column (2)

Net Daily Water Savings Per Toilet — Column (8) = Column (3) ÷ Column (4)

Net Daily Water Savings Per Capita — Column (9) = Column (3) ÷ (Column (6) + Column (7))

Inferred Daily Flushes Per Capita — Column (10) = Column (9) ÷ 1.9 gallons saving per flush

†Approximately half to two-thirds of full-time staff is on patrol duty.

‡Total staff in a 24 hour period, i.e., three shifts.

¥Includes Pools (2), Comfort Station (1), Recreation Centers (19), Senior Centers (4), Miscellaneous (5).

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After all of the above edits, sites with good, complete data were available in only seven out of the total ten categories described in Table I-1. The sample of 70 sites on which the water savings estimates are based do not contain any public buildings classified as either Offices, Lifeguard Stations, or Utility Yards.

Table II-1 summarizes the key findings of this study. The net impact of the program was estimated as the percentage reduction in water use that occurred following toilet retrofits. Significant differences were found in these percentage decrements between Police Stations, Libraries and Fire Stations. However, the percentage reduction in water use resulting from retrofits in Pools, Comfort Stations, Recreation Centers, Senior Centers and other miscellaneous sites were not significantly different among one another. Thus, the latter were combined into a single group.

Table II-1 also converts the estimated percentage reduction factors into savings per toilet and savings per capita. The estimates show that among the 70 analyzed sites, average water savings per toilet averaged approximately 76.8 gallons per day. However, there is considerable variation in estimated water savings across the retrofitted sites.

Toilet retrofits in Police Stations were the least effective. They saved only slightly over 20 gallons per toilet. Even though the water savings estimate for Police Stations is less precise than the other categories because of small sample size, these results are not surprising. On average, Police Stations had a full-time staff of approximately 198 individuals. We estimate based upon informal conversations, that approximately half to two-thirds of them spend most of their time on patrol. Furthermore, Police Stations appear to be well equipped with both toilets and urinals. Thus, water savings expressed either on a per-toilet or per-capita basis are, not surprisingly, low.

On the water saving effectiveness scale, Fire Stations are a rung above Police Stations. On average, a toilet retrofit in a Fire Station saved approximately 28.3 gallons per day. When re-expressed on a per-capita basis, these savings amount to 5.6 gallons per person per day. Since Fire Stations do not entertain a stream of visitors like the other public sites, we can meaningfully infer the number of flushes per person from the per-capita water savings. As mentioned before, almost all pre-existing toilets used 3.5 gallons per flush. So after retrofit with 1.6 gpf toilets, each flush should save 1.9 (3.5-1.6) gallons. Thus, per-capita savings of 5.6 gallons per day translate to 3 flushes per person (5.6 gallons per person/1.9 gallon savings per flush)[1].

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[1]As a point of comparison, we cite Konen's (1985) estimates of flushes per person in one office building based upon direct physical measurements. He concluded that men and women visit restrooms approximately three times during office hours. Women flush three times a day since they use the water closet during every visit. Men flush the water closet once and use the urinals twice. However, a fire station is not like an office building. The office building in question was multistoried with many bathrooms. Estimation of flushes per person was based upon data collected from traffic counters and flush counters from only one floor in the building. In case individuals used restrooms on another floor during the course of their daily work, or during their visit to the cafeteria in the building, it remained unrecorded.

Toilet retrofits in Libraries and the remaining group of public sites pooled together turned out to be some of the most effective in terms of water savings. Savings per toilet averaged 75.9 gallons per day in Libraries and 116.8 gallons per day in the remaining group. These large savings are driven by two very predictable factors: 1) a large number of visitors; and 2) relatively few toilets and even fewer urinals.

It's important to note that savings per toilet, or per capita, are lower in Libraries than the public sites included in the pooled group (i.e., Pools, Comfort Stations, Recreation Centers, Senior Centers, Miscellaneous) even though Libraries ostensibly report having a greater number of visitors. Sheer numbers of visitors by itself can be misleading because it tells us nothing about the length of time these visitors spend at a site. Based upon anecdotal evidence, we believe that visitors at a Recreation Center or Senior Center spend more time at the site than visitors at a Library. Moreover, visits to Recreation Centers are usually coupled with food and beverage consumption unlike visits to a Library. Visits to a comfort station are largely motivated by a desire to use the restrooms. Thus, it's not terribly surprising to find toilet retrofits in Libraries saving somewhat less water even though they report catering to a larger number of visitors.

Per-capita estimates of water savings and inferred flushes per person are provided for the purpose of comparison across categories. These estimates have a clear meaning only in the case of Fire Stations because only Fire Stations have a stable staffing level around the clock and do not cater to any visitors. At Fire Stations, we estimate that each person flushes approximately 3 times a day (i.e., an eight hour shift). The most significant implication of these per-capita water savings estimates or inferred flushes per person is that they clearly point to the folly of depending on some simplistic methodology for quantifying water savings from toilet retrofits in the non-residential sector. The non-residential sector is much more heterogeneous than the residential sector and must be treated as such.

III. CONCLUSIONS

Under the auspices of the Public Facilities Toilet Retrofit program, the City of San Diego earmarked 350 public buildings for toilet retrofits. By March 1994, 195 buildings of the total had been retrofitted. Based upon a detailed statistical evaluation of 70 sites for which complete data were available, we conclude that this program was very effective at saving water. Almost all pre-existing toilets used 3.5 gallons per flush. On average, retrofit with ULF toilets yielded approximately 76.8 gallons per toilet per day. This water-savings performance is far superior to what has been achieved through toilet retrofit programs in the residential sector.

However, a high level of average water savings per toilet can be deceptive. We found considerable variation in water savings achieved by toilet retrofits across the different sites included in the study. This variation in water savings creates tremendous problems for forecasting the efficacy of non-residential toilet retrofit programs. But the variation in water savings also followed some very predictable patterns. Some of the key determinates of water savings are:

1) number of toilets;
2) number of urinals;
3) number of full-time employees and visitors;
4) the amount of time visitors spend at a particular site;
5) the number of hours per day and days per week a facility is operational.

In addition to these five factors, the flushing volume of existing toilets and the gender composition of employees and visitors are obviously two additional key predictors of water savings. Almost all toilets in the analyzed public facilities used 3.5 gallons per flush prior to the retrofit. But, data on gender were unavailable.

Some more specific findings can be drawn from the statistical evaluation.

- Toilet retrofits in Police Stations were the least effective, saving only slightly over 20 gallons per toilet per day. This was largely a result of Police Stations being well equipped with toilets and urinals, even though over half to two-thirds of the staff is on patrol duty.

- Water savings achieved in Fire Stations were slightly higher—approximately 28.3 gallons per toilet per day. Few toilets and even fewer urinals, combined with a round-the-clock operational schedule, were largely responsible for these higher savings even though the staffing level in Fire Stations is lower than Police Stations.

- Toilet retrofits in Libraries saved approximately 75.9 gallons per toilet per day. These Libraries cater to a large number of individuals and have relatively few toilets, and even fewer urinals, driving the savings per toilet upwards.

- The greatest savings were achieved by toilet retrofits in sites such as Recreation Centers, Senior Centers, Pools, Comfort Stations and other miscellaneous sites.

On average toilet retrofits in these sites saved approximately 116.8 gallons per toilet per day. Again, the large number of visitors that have contact with these sites, and the relatively long time they spend at the site, are the primary explanations for these high savings.

Water savings were also re-expressed on a per-capita basis and number of flushes per person inferred from these per-capita savings estimates. These estimates have clear meaning only in the case of Fire Stations because of the absence of visitors. In Fire Stations we estimate that each person flushes a toilet approximately 3 times a day (i.e., during an eight hour shift). Comparable estimates for the other sites are very different.

The water savings estimated in this study clearly show that although toilet retrofit programs in the non-residential sector are likely to be very effective, it is dangerous to apply simplistic formulas for deriving water savings from these programs. Water savings potential varies considerably across sites, albeit in predictable ways. The determinants of toilet-retrofit water savings have been identified here and in previous studies. Future research must attempt to create a classification scheme that meaningfully ranks non-residential buildings on the seven determinants of water savings that have been identified in this study. Without such a classification scheme, predicting overall water savings or targeting retrofit programs will be nigh impossible.

Options For Future Research

The immediate objective of future research must be to extend the analysis presented here to other types of non-residential sites such as Office buildings, Schools and Stadiums that were not included in this study. Such sites have been retrofitted under the auspices of the Public Facilities Retrofit Program in other parts of San Diego County. If appropriate data are available, water savings achieved at these sites should also be analyzed. However, a two-pronged approach may be more suitable.

Our experience with this study suggests that many public sites end up being discarded from the statistical analysis because of incomplete data. This is a shame since one does not have very many public facilities to begin with unlike the thousands of households available in the residential sector. Thus, it may be worth pursuing two separate research tracks. We firmly believe that reliable estimates of water savings can only be obtained through a billings analysis. However, in those sites where either the billings or site characteristics data are incomplete, it may be worth installing traffic and flush counters to corroborate the results of the statistical evaluation. If comparable results are obtained from both methods, confidence in the results of the statistical evaluation will increase to a level far higher than what would normally be warranted from a relatively small sample.

Lessons From the Field

Although program implementation issues are beyond the scope of this study, we have included in Appendix B a short list of 'pointers' developed by the San Diego County Water Authority. These pointers are based upon feedback received from the City of San Diego and the County Water Authority's other member agencies. This practical feedback should be of great aid to water conservation managers and planners.

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APPENDIX A: STATISTICAL MODELS OF WATER DEMAND

Introduction

The fixed-effects water use model used to evaluate the impact of the Public Facility Retrofit program relates water use in a public building to season, climate, site-specific indicator variables (fixed effects), interactions of the above with a drought-period indicator variable, and an indicator for participation in the toilet retrofit program. The coefficient on the participation indicator then provides a measure of the net reduction in water use as a result of the toilet retrofits.

The functional relationships among the above factors are estimated from historical water use data starting December 1988 and going through March 1994. To estimate the impact of climate on water use as accurately as possible, we allowed the nature of the available water use data from billing system records to dictate the structure of our models, not the reverse. Although water meters are read on a predetermined cycle (usually bi-monthly), the cycles do not represent the same calendar period for each public building. Researchers in the past have avoided this problem by changing the structure of the data, either by aggregating water use to an annual level or by prorating water use data to a monthly level. Both techniques attenuate the "peaks" and "valleys" normally displayed by water use and thus wipe out important information about the impact of climate on water demand.

To avoid this problem, we specify the conceptual water use model at a daily level, not a bi-monthly level. By working with daily climate data, we construct an appropriate bi-monthly measure of climate that corresponds to the same calendar period that a customer's meter reading represents. Geographic climatic differences are captured by working with two different weather stations, one for the cooler coastal areas of the City and one for the hotter inland areas.

The water use model can capture separate effects for rainfall and temperature, and it allows for these contemporaneous effects to vary through the year. (Temperature, for example, affects water demand differently in the winter than in the summer.) The water use model can detect lagged effects of climate; rainfall two months ago may affect water demand today. Thus, working with daily climate data produces an accurate representation of climate on water use as measured at the meter.

Lastly, since the statistical analysis is predicated on metered water use, we gathered additional data on when a meter is repaired or retrofitted. Meter repairs or retrofits usually result in increased metered water consumption. Most utilities have meter repair and retrofit programs because meter sensitivity to water flow, especially low flow, declines with age. The City of San Diego maintains a data base in their customer billing system that contains information about the last date each customer had a meter retrofit. They made this data available to us. Meter retrofit information turned out to be a statistically significant predictor of water use among the public sites analyzed in this study.

Model Structure

This section describes the structure of our water use model and the statistical methodology used to estimate the model.

D-045487

The water demand model is of the form:

$$\ln U_{it} = F(C_t, S_t, TA_i \times C_t, TA_i \times S_t, S_t \times D, TA_i \times S_t \times D, \mu_i, \mu_i \times D, Part) + \varepsilon_{it} \quad (1)$$

where U_{it} is the bi-monthly water use of the i th customer in the t th time period. C_t and S_t are measures that capture the response of water demand to climate and season respectively. The derivation of the climate and seasonal variables is described in detail in the following subsection.

Public sites with turf area (TA_i) should show greater response to both climate and season. Thus, turf area is interacted with the climate and seasonal variables to capture the differential response between sites that have no turf area and those that do.

Evaluation of a conservation program where part of the data is tainted by the drought poses special analytic problems. Drought conditions reduced every sites' water consumption level, more so in the summer than winter months. But not necessarily in similar or equal amounts. It is natural to expect sites with larger turf areas to show a greater response to the drought on both an absolute and proportional scale.

Drought response is captured through multiple interactions. First, the seasonal variables (S_t) are interacted with an indicator variable (**D**) that takes on the value of one for the drought and post-drought period. Second, the interaction between the seasonal measures and the drought indicator are further interacted by turf area to capture the greater response of such sites to the drought. Similar interactions were also included for the climate measures, but they turned out to be statistically insignificant.

The site specific fixed effects (μ_i) capture the average difference in water consumption levels among the analyzed sites. Thus, the impact of all unmeasured characteristics that influence a site's water use are captured by these fixed effects. These site-specific fixed effects are further interacted by the drought indicator variable (**D**) to capture the differential impact of the drought across the different sites. Interactions between the fixed effects and the drought indicator in essence capture that portion of the drought response that is site specific and remains unaccounted for by interactions between the seasonal measures, turf area and the drought indicator. Inclusion of these interactions ensures that net program impacts are estimated as the climate-corrected difference between post-retrofit water use and average water use only during the drought, not average water use during the entire pre-retrofit period. Comparing post-retrofit average water use to the entire pre-retrofit history would vastly overstate program impacts in the absence of a control group.

After accounting for all the factors that affect water use prior to the retrofits, the net impact of the program is estimated through a participation indicator variable (**Part**) that takes on the value of one for meter reads recorded two months after the retrofit date. This participation indicator can be interacted with additional indicators of site type (e.g., Libraries, Police Stations, Fire Stations, and so on) to capture the differences among net water savings achieved among these sub-groups of retrofitted public buildings.

Model error (e_{it}) in Equation 1 should be normally distributed and have constant variance (i.e., the error should not be heteroscedastic). Examination of model error revealed that the latter condition was not met by the data. Error variance appeared to vary significantly by site type. Thus, an appropriate heteroscedasticty correction was developed based upon methods described in Carroll and Ruppert (1988). The statistical model was estimated using Generalized Least Squares (GLS) that incorporates this correction.

Specification of Continuous-Time Seasonal and Climatic Measures

In this section we discuss the derivation of the seasonal and climatic measures that enter the water use model. These models have several unique features. First, seasonal and climatic effects are specified as a continuous (as opposed to discrete monthly or bi-monthly) function of time. Though this requires working with daily climate data, it greatly increases the precision of the water use model through a precise time matching of water use and climate. Second, by using separate measures of climate for the coastal and inland geographical areas, additional spatial climatic variation enters into the models. Third, the models permit interactions of time-invariant customer characteristics (e.g., turf area) with seasonal and climatic components. Thus, the climatic response of demand can be made to vary across sub-groups of customers.

Because water use in San Diego's public buildings is measured either on a one- or two-month cycle, our water use model uses explanatory variables that match the consumption period covered by the meter read. Thus, if a two-month-cycle customer's meter is read on October 15, the meter reading represents water use in the previous two months, approximately from August 15 to October 15. The associated explanatory variable of precipitation should also represent how much rain fell in this same period. We specify the demand function at a daily level that permits a consistent time matching.

A Fourier series defines the seasonal component of the model. For a given day ***T*** and a harmonic index ***j*** we define the following harmonics:

$$\sum_{j=1}^{6}\left\{\beta_{1,j}\sin\left(\frac{2\pi jT}{365}\right)+\beta_{2,j}\cos\left(\frac{2\pi jT}{365}\right)\right\},\quad \text{where}\quad T=(1,...,365). \tag{2}$$

We then take a 61-day—or 31-day for a one-month-cycle customer— moving average of each harmonic to yield a consistent measure of constant seasonal component for meter-read water use. Because the lower frequencies (j<=2) tend to explain most of the seasonal fluctuation, the higher frequencies can be omitted with little predictive loss.

The models incorporate two types of climate measures: air temperature and rainfall. We use the average maximum daily temperature and the total amount of rainfall in the 61-day meter reading cycle.[2] The 61-day measures of temperature and rainfall are then logarithmically transformed to yield:

$$\ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\} \quad , \quad \ln\left\{\sum_{t=T}^{T-61} Temp_t\right\} \tag{3}$$

These measures of climate in a 61-day period can be reexpressed as a historic mean and departure from historic (geometric) mean. The historical geometric mean applicable for a given 61-day billing period is based on the average of climate that prevailed during similar 61-day periods from 1948 to 1990. Subtracting the (geometric) mean, we express climatic deviations as:

$$\begin{gathered} \ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\} - \overline{\ln\left\{1 + \sum_{t=T}^{T-61} Rain_t\right\}} \ , \\ \ln\left\{\sum_{t=T}^{T-61} Temp_t\right\} - \overline{\ln\left\{\sum_{t=T}^{T-61} Temp_t\right\}} \end{gathered} \tag{4}$$

By constructing the climatic measures in this deviation-from-mean form, they are made independent of the seasonal effect. (If the means were not subtracted, there would be a strong correlation between season and climate.) Thus, the constant seasonal component of the model captures all constant effects including normal climate effects.

In processing the billing histories, we encountered relatively few meter readings that were estimated. But, these were not ignored. If in the billing history an actual reading followed an estimated reading, the two were combined to create a two- or four-month average daily use. This took care of most estimated readings. For such combined readings, the climate and seasonal variables were also calculated to correspond to the two- or four- month period in question. Thus, great care was taken to use as much water use data as possible without tampering with the climate and seasonal patterns implicit in these data.

The model's ability to capture the impact of season and climate can be further enhanced by allowing the contemporaneous effect of climate to vary though the season.[3]

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[2]Our climate measures are constructed from daily rainfall and temperature readings taken at two NOAA weather stations: 1) San Diego airport near the coast; and 2) Escondido for the inland areas.

[3]We allow for seasonality in the climatic effects by interacting the climatic measures with the harmonic terms. The same effect could be achieved, at some loss in model parsimony, by interacting climate with seasonal indicator variables.

In addition, the model can also capture lagged effects of rainfall. Thus, the effect of rainfall two months prior to a billing period can easily be estimated in the general framework outlined here.

Discussion of Model Results

The estimated model on which this study's conclusions are based is shown in Table A-1. This model's robustness was thoroughly examined by subjecting it to extensive diagnostics and sensitivity analysis.

Since the starting point of the drought was unclear, we estimated the model with different assumptions about when the drought began. The advent of the drought was varied from April 1990 until October 1990. The results were not significantly sensitive to these assumptions. Water use was lowest at the peak of the drought during the summer of 1991. Since then water use has crept back up towards its historical norm only very slowly. Lack of a control group to capture this slow increase in baseline water use since the summer of 1991 should lead to a downward bias in the estimate of net program impacts. But, the sensitivity analysis suggests that this bias is minimal, if present at all. For the final model we have assumed the drought began in May 1990. The model was tested for influential observations and influential sites. A very large site with over 30 toilets had to be excluded for this reason. Finally, the model was subjected to an omnibus specification test suggested by Ramsey (1969) to detect residual non-linearities. No residual non-linearities were found in the model specification.

The net impact of the toilet retrofits is captured by the participation indicator variable and its interactions with the site-type indicators. We were able to detect differences in savings only between Police Stations, Fire Stations, Libraries and the residual group containing Senior Centers, Pools, Comfort Stations and a few other miscellaneous sites. The reported coefficients on the participation indicators suggest that as a result of the program, water consumption fell by 5.25 percent in Police Stations; 9.1 percent in Fire Stations; 14.5 percent in Libraries; and 24.1 percent in the sites that comprise the residual group. The coefficient on the participation indicator shows net savings among sites that comprise the residual group. To derive savings for Police Stations, Fire Stations, and Libraries, the coefficients on their respective interactions with the participation indicator must be added with the coefficient on the overall uninteracted participation indicator variable. Thus, for example, percentage change in Police Stations' water consumption can be derived as $(\exp(-0.276 + 0.222) - 1) \times 100$, or a reduction of 5.25 percent[4].

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[4]When the dependent variable is in logarithmic form, coefficients on indicator variables have to be exponentiated before they can be interpreted as percentage changes. Theoretically, a small correction for the standard error of the coefficient also enters the formula for converting indicator variable coefficients to percentage changes (Goldberger [1968]). But, this standard error correction is so small that it can almost always be ignored. The formula for deriving percentage changes then is: $\exp(\beta-\sigma^2/2) - 1$ where β is the reported coefficient and σ is the standard error of the coefficient. If the standard error is ignored, the formula reduces to exponentiation of the coefficient followed by subtraction of one.

Table A-1 Estimated Fixed Effects Water Demand Model

Variable	Coefficient	Standard Error	t-statistic
	β	σ	β/σ
Intercept	8.8461	0.1038	85.17
Participation indicator (=1 if participant)	-0.2757	0.0298	-9.24
Participation indicator * Police Station indicator	0.2220	0.1080	2.05
Participation indicator * Library indicator	0.1192	0.0461	2.58
Participation indicator * Fire Station indicator	0.1803	0.0470	3.83
First Sine harmonic, 12 month (annual) frequency	0.0580	0.0204	-2.83
Second Sine harmonic, 6 month (semiannual) frequency	0.0210	0.0211	0.99
First Cosine harmonic, 12 month (annual) frequency	-0.1940	0.0210	-9.21
Second Cosine harmonic, 6 month (semiannual) frequency	0.0006	0.0214	0.02
Ln(turf area) * First Sine harmonic	-0.0204	0.0030	-6.65
Ln(turf area) * Second Sine harmonic	-0.0080	0.0032	-2.49
Ln(turf area) * First Cosine harmonic	-0.0206	0.0032	-6.25
Ln(turf area) * Second Cosine harmonic	-0.0009	0.0032	-0.27
Deviation of Ln(temperature) from its bimonthly mean	0.7932	0.2977	2.66
Deviation of Ln(1+rain) from its bimonthly mean	-0.0920	0.0333	-2.76
Two month lag of rainfall deviation	0.0283	0.0248	1.14
Ln(turf area) * Temperature	0.1310	0.0450	2.90
Ln(turf area) * Rainfall	-0.0181	0.0041	-4.35
Ln(turf area) * two-month lagged rainfall	-0.0194	0.0037	-5.11
Drought indicator * First Sine harmonic	-0.0428	0.0279	-1.53
Drought indicator * Second Sine harmonic	-0.0019	0.0275	-0.07
Drought indicator * First Cosine harmonic	0.0550	0.0264	2.08
Drought indicator * Second Cosine harmonic	0.0036	0.0275	0.13
Drought indicator * Ln(turf area) * First Sine harmonic	0.0056	0.0041	1.33
Drought indicator * Ln(turf area) * Second Sine harmonic	0.0048	0.0040	1.18
Drought indicator * Ln(turf area) * First Cosine harmonic	-0.0093	0.0041	-2.26
Drought indicator * Ln(turf area) * Second Cosine harmonic	0.0016	0.0041	0.40
Temperature * First Sine harmonic	0.4003	0.2890	1.38
Temperature * First Cosine harmonic	-0.2888	0.2885	-1.00
Rainfall * First Sine harmonic	0.0193	0.0346	0.55

Variable	Coefficient	Standard Error	t-statistic
	β	σ	β/σ
Rainfall * First Cosine harmonic	0.0785	0.0296	2.65
Meter retrofit indicator	0.0694	0.0316	2.19
Total variance explained (R-square) Variance explained by site-specific fixed effects and interactions between fixed-effects and drought indicator	93.8 percent 80.6 percent		

The coefficients on the seasonal and climate terms follow very predictable patterns. Public sites with turf area are significantly more responsive to both season and climate than sites without turf area. For sites with turf area, one can even detect lagged effects of rainfall in the prior two month period.

Interactions of the seasonal terms with the drought indicator and second order interactions with turf area do not pick up strong effects. This should not be interpreted to mean that drought response was negligible. Many of the interactions between the site-specific indicators and the drought dummy were significant suggesting that each site responded differently to the drought. Thus, overall measures of drought response (i.e., interactions between the seasonal measures, drought indicator and turf area) are not very satisfactory. Allowing for site-specific drought response is critical for reliably estimating the net impact of the program.

Lastly, we include a meter-retrofit indicator variable that captures the jump in water use that normally occurs when an old meter is retrofitted. Among the analyzed public sites, metered water consumption rose by approximately 7.2 percent after a meter retrofit. This is a significant increase. Ignoring this increase in recorded water consumption biases the estimate of net conservation downwards.

APPENDIX B: LESSONS FROM THE FIELD

D-045495

The San Diego County Water Authority has collated key feedback received from the field into a set of 'Retrofit Program Pointers.' We are reproducing their findings below since it is of practical relevance to water conservation managers who are planning to implement non-residential toilet retrofit programs. We are grateful to Diane Parham and Maria Mariscal for sharing this information with us.

- Note any potential toilet removal obstacles. Is the toilet targeted for retrofit easily removable? Some wall-hung models require access to pipes and valves located behind walls.

- Primarily in older buildings, the risk of encountering asbestos hazards is a real possibility. Check with individual building supervisors/maintenance personnel, the local office of planning, or department of hazardous materials to determine if the building(s) targeted for retrofit are potential asbestos risks. If determined that exposure to asbestos may occur, proper safety precautions should be taken.

- Maintain a toilet maintenance service record for all devices retrofitted. List the location of all the installed devices and service calls made to the newly installed and existing toilets (for toilet model quality control purposes).

- Purchasing toilets in bulk quantities will result in volume-purchase price discounts. It is suggested that if a central purchasing department exists, the participating public facilities coordinate their individual purchase orders with the central purchasing department/office.

- Check with all local building, health, and planning departments to assure that the toilet fixtures proposed to be installed meet all installation requirements (e.g., in some public facility applications only round toilet models can be used).

- Before retrofitting a hi-rise building, check each floor's individual water pressure to ensure an adequate amount of water pressure (just as in instances of low water pressure, in some circumstances, excessive pressure levels will also not allow the toilet valves to function properly).

Problem areas that have been identified by current program participants include:

- Unexpected expenses. Need for additional, unexpected accessory items such as vacuum breakers and toilet seats.

- The need for leak-proof wax rings vs. plain wax rings. Results have shown that there is a significant difference in performance between the two types of rings.

- Difficulty in finding commercial, wall-hung, ceramic, three-bolt carrier toilets. Manufacturers are gradually beginning to address the need for this type of toilet. Residential wall-hung models are even more difficult to locate. However, a substantial number of wall-hung stainless steel models are available.

- On some wall-hung toilets, the ceramic base is too thick. A solution is to unscrew the carrier bolts out 1 inch. Some bolts are rusted and cannot be unscrewed. This should be considered when purchasing toilets.

- In a few instances, the footprint for the wall mounted ULF toilets will be larger than for the existing, older toilet models. Take note of this potential sizing discrepancy.

- There may be need for handicapped toilet models. Take inventory of the existing toilet fixtures and order the appropriate toilet models for each respective toilet retrofit.

APPENDIX C: SURVEY FORM

D-045498

City of San Diego
City Facilities Retrofit Program

Facility #:	Facility Name:
Service Address:	
Account(s) Numbers:	
Contact Name:	
Contact Title:	
Contact Department/Division/Section:	
Contact Telephone:	

Facility Profile

	Initials	Date	P/F/C
1. How many persons are currently employed at this facility?			
2. Per day, approximately how many members of the public (if any) use the facility?			
3. On average, how many days per week is the facility operational?			
4. What category best describes this facilities' operations?			
Library / Offices / Police / Pool / Fire Lifeguard / Comfort Station / Rec Center Utility Yard / Other (Specify)			
5. What year was the building constructed?			
6. Are other facilities on the same account number? (Circle one) Yes No Specifiy facility name(s)			
7. Does this facility have a separate irrigation meter? (Circle one) Yes No If Yes, go to question 12. If No, go to question 8.			
8. What is the size of the turf area, if any, in square feet?			
9. Does the facility have an in ground sprinkler system? (Circle one) Yes No			
10. If so, does the sprinkler system have an automatic timer? (Circle one) Yes No			
11. Approximately how many days per week does the turf get watered?			
12. What is the total number of toilets in this facility? Flushometer valve________ Tank ________			
13. What is the total number of ultra-low flush toilets in this facility? Flushometer valve________ Tank ________			
14. When were the ultra-low flush toilets installed? (Day/Month/Year) From________ To ________			
15. What is the total number of urinals in this facility?			
16. What is the total number of showers in this facility?			
17. What is the total number of low-flow showerheads in this facility?			

Reviewed by ________________

Supervising Water Conservation Analyst ________________

Copy to File ________________ Copy to A&N ________________

Legend: **P** *for phone contact*
F *for field investigation*
C *for computer database*

(PLEASE INITIAL AND DATE AFTER EACH ACTION)

DLP-Water Conservation 10/98

D-045499

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